Sediment Transport Modeling and Application for Ocean Beach and San Francisco Bight, CA

H. Li[1], L. Lin[1], F. Wu[2], L. C. Andes[2], and J. G. Zoulas[2]

[1]U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180; PH: 601-634-2840; FAX: 601-634-3080; email: Honghai.Li@usace.army.mil, Lihwa.Lin@usace.army.mil

[2]U.S. Army Corps of Engineers, San Francisco District, 1455 Market Street, San Francisco, CA 94103; PH:415-503-6902; email: Frank.Wu@usace.army.mil, Lisa.C.Andes@usace.army.mil, James.G.Zoulas@usace.army.mil

ABSTRACT

The U.S. Army Corps of Engineers (USACE) San Francisco District (SPN) and Coastal Inlets Research Program (CIRP) are presently performing hydrodynamics, wave, and sediment transport numerical modeling study with the Coastal Modeling System (CMS) to evaluate a designated dredged-material placement site nearshore the beach erosion hot spot and onshore nourishment alternatives on Ocean Beach, California. Both model results and measurements reveal that tidal forcing is the main process in the nearshore area where the tidal current is predominantly along the shoreline. The calculated sediment transport shows more longshore movement than cross-shore shoreward the dredged-material placement site. The model result also indicates significant sediment erosion at Ocean Beach.

INTRODUCTION

Ocean Beach is located on the coast of San Francisco, California, to the south of the Golden Gate, and in the shadow of the San Francisco Ebb Tidal Delta (Figure 1). It is part of the San Francisco Littoral Cell that includes the outer ebb tidal bar of San Francisco Bay and the sandy waterfront on the north and west sides of San Francisco. High energy waves and human perturbation have induced significant sediment transport and resulted in periodic erosion at Ocean Beach adjacent to the southern-most lobe of the Ebb Tidal Delta. The erosion hotspot had threatened the structural integrity of the adjacent highway and ocean outfall pipe.

The SPN has designated a temporary nearshore dredged-material placement site located about 750 m offshore and slightly south of the erosion hot spot, in depths between approximately 9 and 14 m (Figure 1). This site, known as SF17, was chosen because strong tidal current and coastal waves in the area may have the potential to move the sediment toward the beach that was experiencing substantial erosion. The nearshore placement site can prevent further scour on the exposed outfall pipe. The U.S. Geological Survey (USGS) has monitored and studied the sediment transport and morphology change at the designated site since May 2005 (Barnard et al. 2009). Up to the present day, a total sediment load of about 700,000 m^3 has been placed in SF17, approximately

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14. ABSTRACT
The U.S. Army Corps of Engineers (USACE) San Francisco District (SPN) and Coastal Inlets Research Program (CIRP) are presently performing hydrodynamics, wave, and sediment transport numerical modeling study with the Coastal Modeling System (CMS) to evaluate a designated dredged-material placement site nearshore the beach erosion hot spot and onshore nourishment alternatives on Ocean Beach, California. Both model results and measurements reveal that tidal forcing is the main process in the nearshore area where the tidal current is predominantly along the shoreline. The calculated sediment transport shows more longshore movement than cross-shore shoreward the dredged-material placement site. The model result also indicates significant sediment erosion at Ocean Beach.

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400,000 m^3 of which has remained within the placement site.

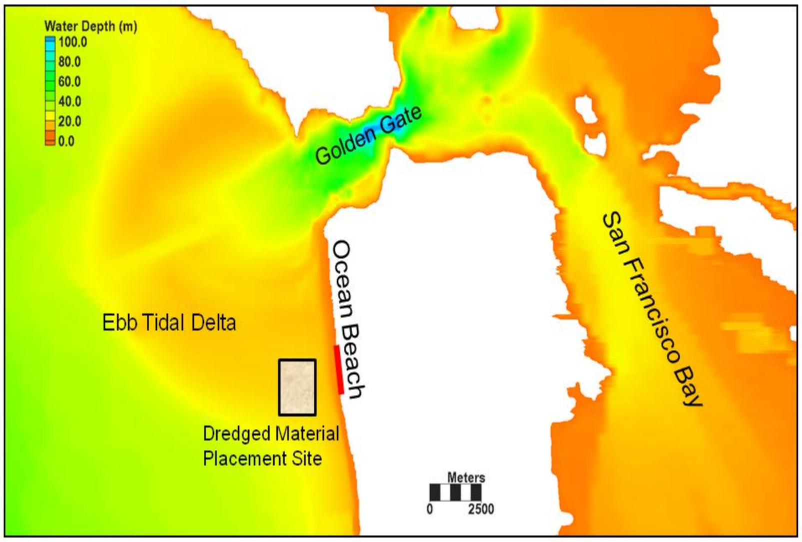

Figure 1. Study area.

OBJECTIVES

To remediate beach erosion and shoreline recession at Ocean Beach, it is necessary to designate a permanent nearshore placement location for a beneficial reuse of dredged material. USACE/SPN and USACE/CIRP are performing hydrodynamics, waves, and sediment transport numerical modeling study with the Coastal Modeling System (CMS) to evaluate the feasibility of such a placement site and the designated dredged-material placement site nearshore Ocean Beach. The offshore location was chosen because the strong tidal current and open-ocean waves in the area have the potential to feed sediment toward the beach experiencing erosion. The nearshore placement site may prevent further scour on the exposed outfall pipe.

FIELD DATA ASSEMBLY

A wide range of field data, including water levels, waves, current, and topographic mapping, have been collected by SPN and USGS at Ocean Beach and in San Francisco Bight from 2004 through 2010. The assembled data is applied for the CMS setup, and the model calibration and verification.

In January 2010, a set of bathymetric data were collected at Ocean Beach along 18 shore-normal transects by the Coastal Profiling System (CPS) (Barnard et al. 2009). Besides the CPS data, the offshore bathymetry data were extracted from GEOphysical DAta System (GEODAS) coastal grid (NGDC 2009) and multi-beam bathymetry surveys. Those data were used to configure the CMS models. Figure 2 shows the locations of the 18 transects and two CPS sample surveys of Transect 13.

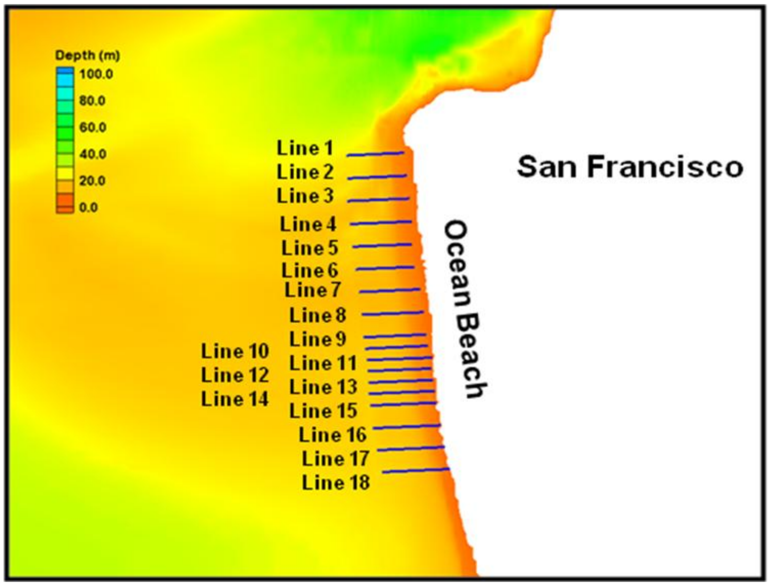

Figure 2. The CPS (18) transects and sample survey data of Transect 13.

Local water surface elevation data are available from two NOAA coastal stations 9415020 (Point Reyes) and 9415144 (Port Chicago), http://tidesandcurrents.noaa.gov (Figures 3 and 4). These water level data indicate a mixed, predominately semi-diurnal tidal regime at the study area. The mean tidal ranges (mean high water – mean low water) at Point Reyes and Port Chicago are 1.19 and 1.12 m, respectively.

Directional wave data are available from two Coastal Buoys No. 46026 and No. 142 maintained by the National Data Buoy Center (NDBC, http://www.ndbc.noaa.gov) and Coastal Data Information Program (CDIP, http://cdip.ucsd.edu), respectively (Figures 3). Figure 5 shows wave information collected at Buoy 46026 in June 20-29, 2005. The predominant waves are from the west-northwest direction. Extreme large waves are rare as more than 98 percent of the wave population shows a height less than 2 m. The average wave height and peak wave period are 0.9 m and 9 sec, respectively. Wind information is collected at Buoy 46026 and is characterized by the west-southwest direction. The mean wind speed is approximately 4 m/sec with an extreme value of 10 m/sec (Figure 6).

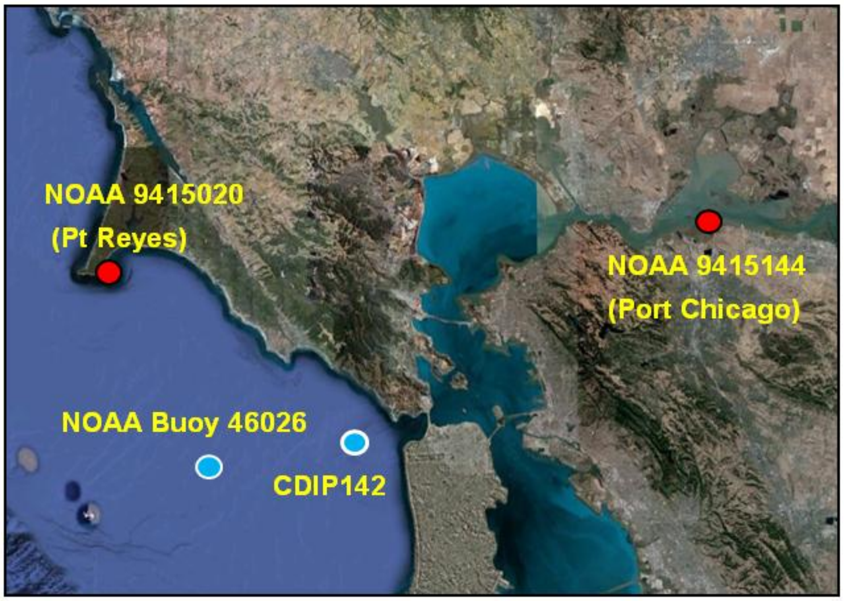

Figure 3. Locations of coastal buoys and tide gages.

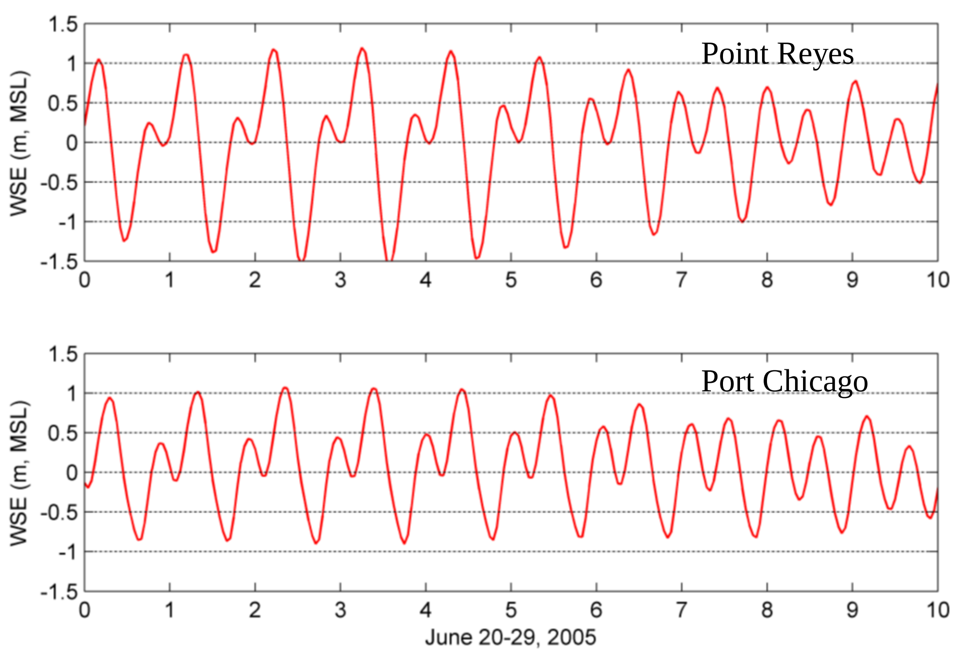

Figure 4. Water surface elevations at Point Reyes and Port Chiacago, CA.

Four Acoustic Doppler Current Profilers (ADCP) were deployed during the summer and winter of 2005 and 2006 (Barnard et al. 2009) to measure current, waves, and water levels. Current and water level data at three nearshore ADCPs (Sites 1, 2, and 3) were used to calibrate the CMS models (Figure 7). The offshore ADCP (Site 4) is too close to the CMS seaward boundary and, therefore, the data collected is not used in the study.

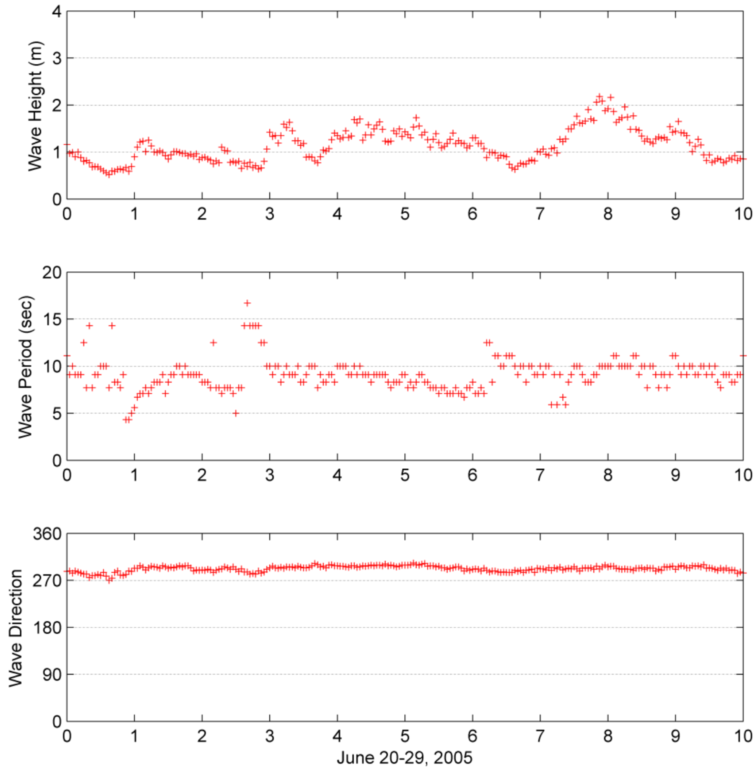

Figure 5. Wave information collected at NDBC Buoy 46026.

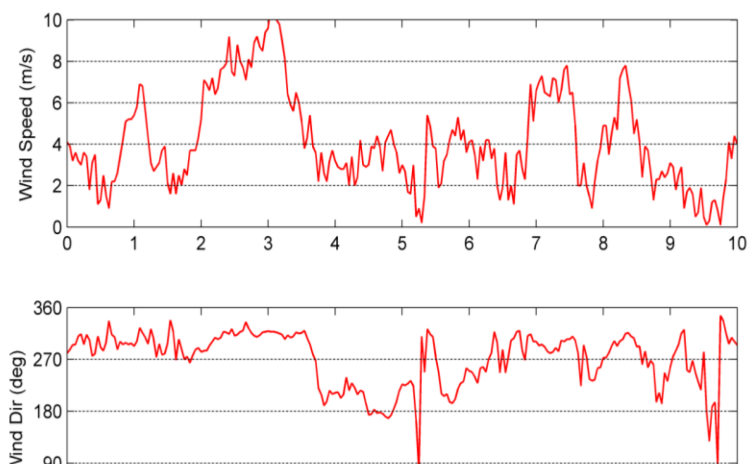

Figure 6. Wind data collected at NDBC Buoy 46026.

Figure 7. Locations of nearshore ADCPs.

COASTAL MODELING SYSTEM (CMS)

The CMS is a suite of hydrodynamics, wave, and sediment transport models including CMS-Flow and CMS-Wave, http://cirp.usace.army.mil/wiki/CMS. Physical processes calculated by CMS-Flow are circulation, sediment transport, and morphology change (Buttolph et al. 2006). CMS-Wave is a two-dimensional wave spectral transformation model that contains approximations for wave diffraction, reflection, wave transmission, wave run-up, and wave-current interaction (Lin et al. 2008). In the present study, CMS-Flow and CMS-Wave were applied to simulate coastal, estuarine, and wave-induced longshore and cross-shore mass transport processes, and to evaluate sediment transport and volume change at the nearshore placement site and Ocean Beach.

Figure 8 shows the CMS rectangular grid domain that consists of 300 $\times$ 541 cells, covering Ocean Beach and San Francisco Bay. The model domain extends approximately 50 km alongshore and 20 km offshore San Francisco Bight. The water depth at the offshore boundary is 80 m. The maximum water depth reaches to more than 100 m at the Golden Gate area. A variable-resolution grid system was created to discretize the nearshore and offshore regions, which permits coarser grid resolution of 400 m in the offshore and finer resolution of 20 m at Ocean Beach.

The CMS is driven by the forcing of the time-dependent open-boundary water surface elevations, offshore incident wave spectra, and buoy wind data. The water surface elevations were specified at open boundary using the data at Point Reyes (NOAA 9415020) and Port Chicago (NOAA 9415144). Wave spectra and wind forcing data were retrieved from NDBC Buoy 46026.

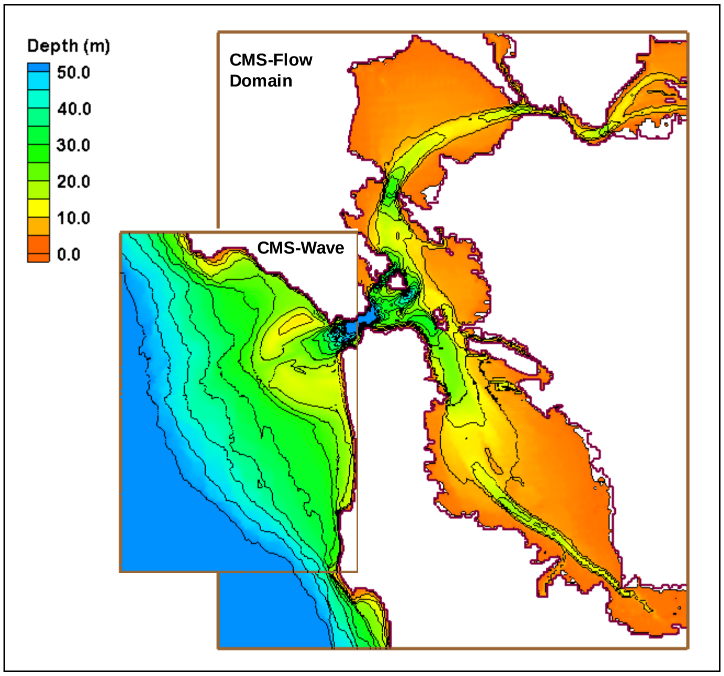

Figure 8. CMS-Flow and CMS-Wave domains.

RESULTS

The CMS simulation was conducted for a 10-day period of 20 to 29 June, 2005. CMS-Flow was calibrated against the ADCP measurements during this summer period, but the CMS-Wave calibration was performed against the CDIP142 buoy data during January 2009 because no wave data were available at this location before 2007. Figure 9 shows that the CMS-Wave results and the measured data at CDIP142 for January 2009. The wave transformation results show a good agreement with the measured wave parameters.

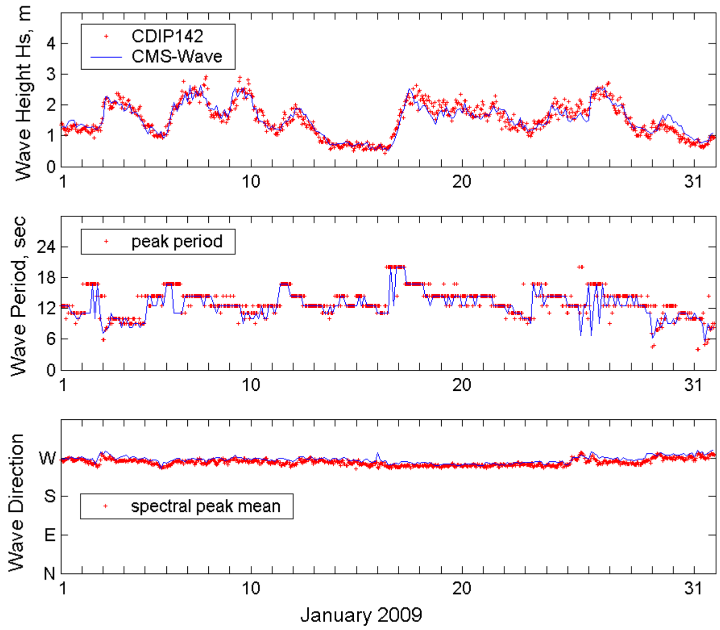

Figure 9. Measured wave parameters at CDIP142 and CMS-Wave results, January 2009.

Figure 10 shows water surface elevation comparisons at Site 3 from 20 to 29 June, 2005. The calculated water levels agree well with the measurements in amplitude and phase. The correlation coefficient between the CMS and the data is 0.99, the root mean square error (RMSE) is 0.11 m, and the relative RMSE (RMSE/Data Range) is 3.8%.

Figure 11 shows the current comparisons at Sites 1, 2, and 3. The tidal current is predominantly longshore and cross-shore component is relatively small. The depth-averaged current magnitude nearshore can reach 1.0 to 1.5 m/sec north of Ocean Beach adjacent to the Golden Gate entrance. The current magnitude decreases to south along Ocean Beach approximately 0.5 m/sec in the nearshore dredged-material placement site (SF17). The CMS reproduces well the current magnitude and direction at Sites 1 to 3. Table 1 presents the correlation coefficient, RMSE, and relative RMSE (RMSE/Data Range) between the calculated and measured currents.

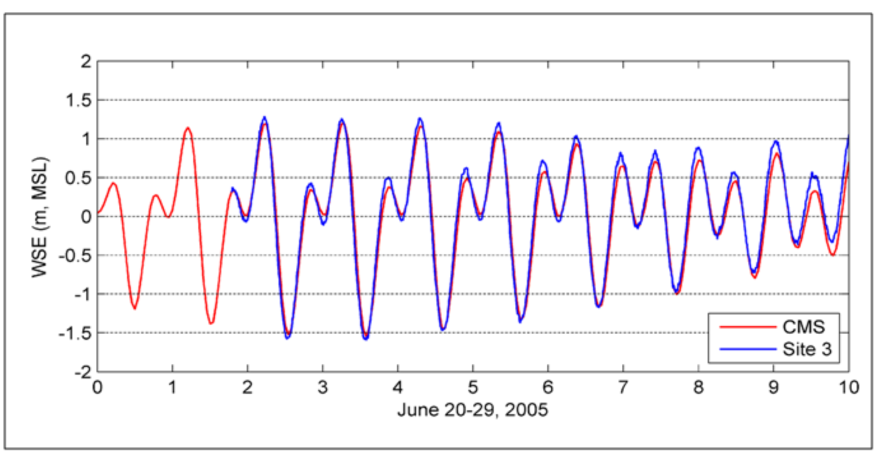

Figure 10. Calculated and measured water levels Ocean Beach, Site 3.

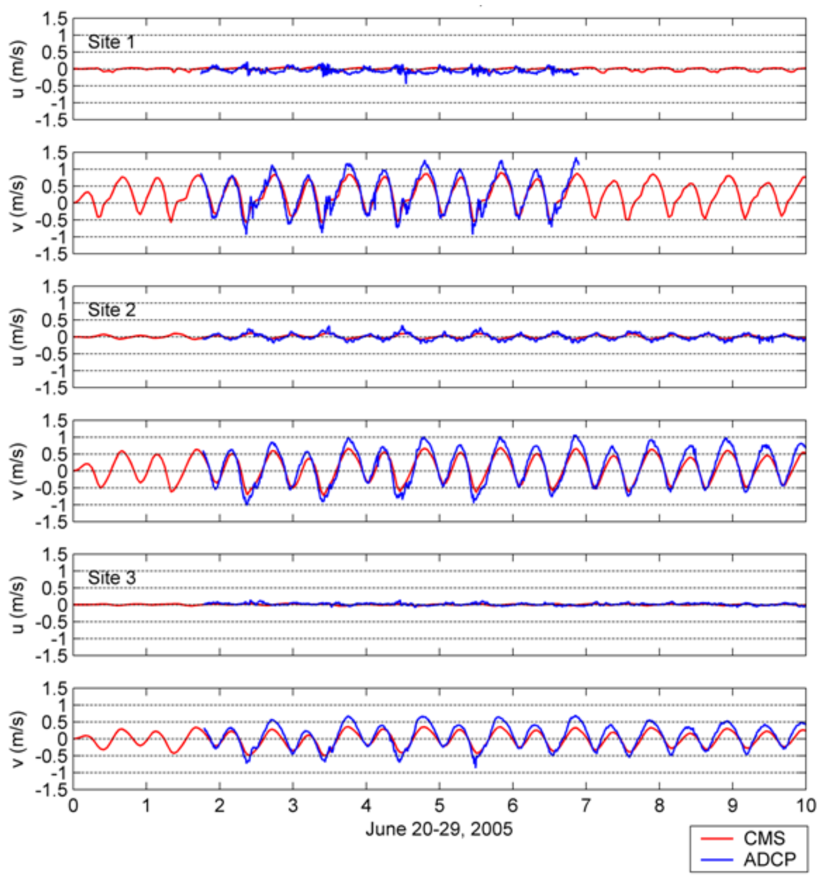

Figure 11. Calculated and Measured currents at Ocean Beach, Sites 1, 2, and 3.

Table 1. Correlation coefficients, root mean square errors (RMSE), and relative RMSEs for computed and measured longshore currents.

Site	Correlation Coefficient	RMSE (m/s)	Rel RMSE (%)
1	0.960	0.176	8.4
2	0.966	0.199	11.1
3	0.963	0.164	11.7

Figure 12 shows wave and wind data at NDBC 46013 and CDIP 142 in January 2010. With passages of winter storms from south and southwest in the study area, the peak wave height and peak wind speed are approximately 8 m and 20 m/sec around 20 January, 2010, respectively. The CMS is conducted to calculate the sediment transport and morphology change to compare with the bathymetry surveys in this period.

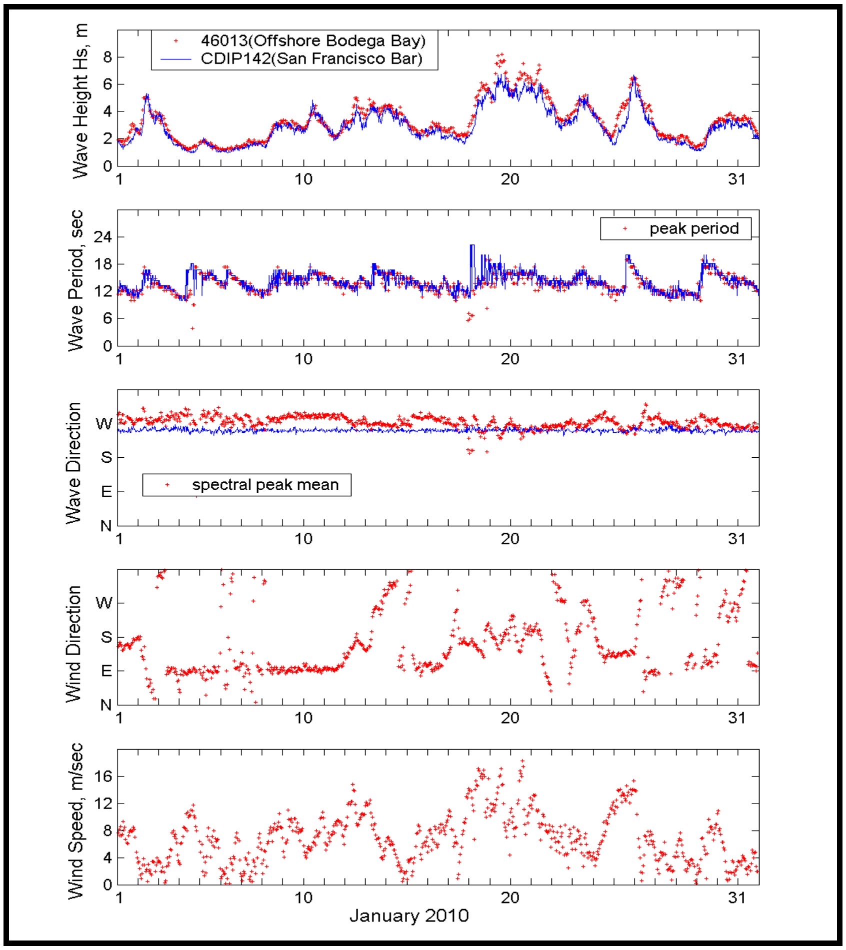

Figure 12. Wind wave data at NOAA 46013 and CDIP142 for January 2010.

Figure 13 shows the calculated morphology change nearshore Ocean Beach from a 25-day simulation of 3 to 28 January, 2010. The model result indicates that storms and coastal processes induce more erosion and accretion in the surf zone. There are clearly onshore and offshore bar movements in the nearshore coastal area. The maximum erosion and accretion are about 3 m along the shoreline. To estimate sediment volume balance, a polygon area was used for the calculation as shown in Figure 13. The calculated morphology change shows a net sediment loss of 790,000 m^3 within the area from the simulation. This calculated sediment volume loss is comparable to the CPS observation .

Sediment volume balance is calculated through the analysis within a rectangular area next to the erosion hotspot at Ocean Beach (Figure 14). The transport at the nearshore dredged-material placement site indicates the onshore sediment movement. Figure 14 shows a strong long-shore sediment transport from south to north. The sediment volume change analysis indicates that nearly half million cubic meters of materials are eroded during the winter storms. This local erosion provides primary source for the longshore transport.

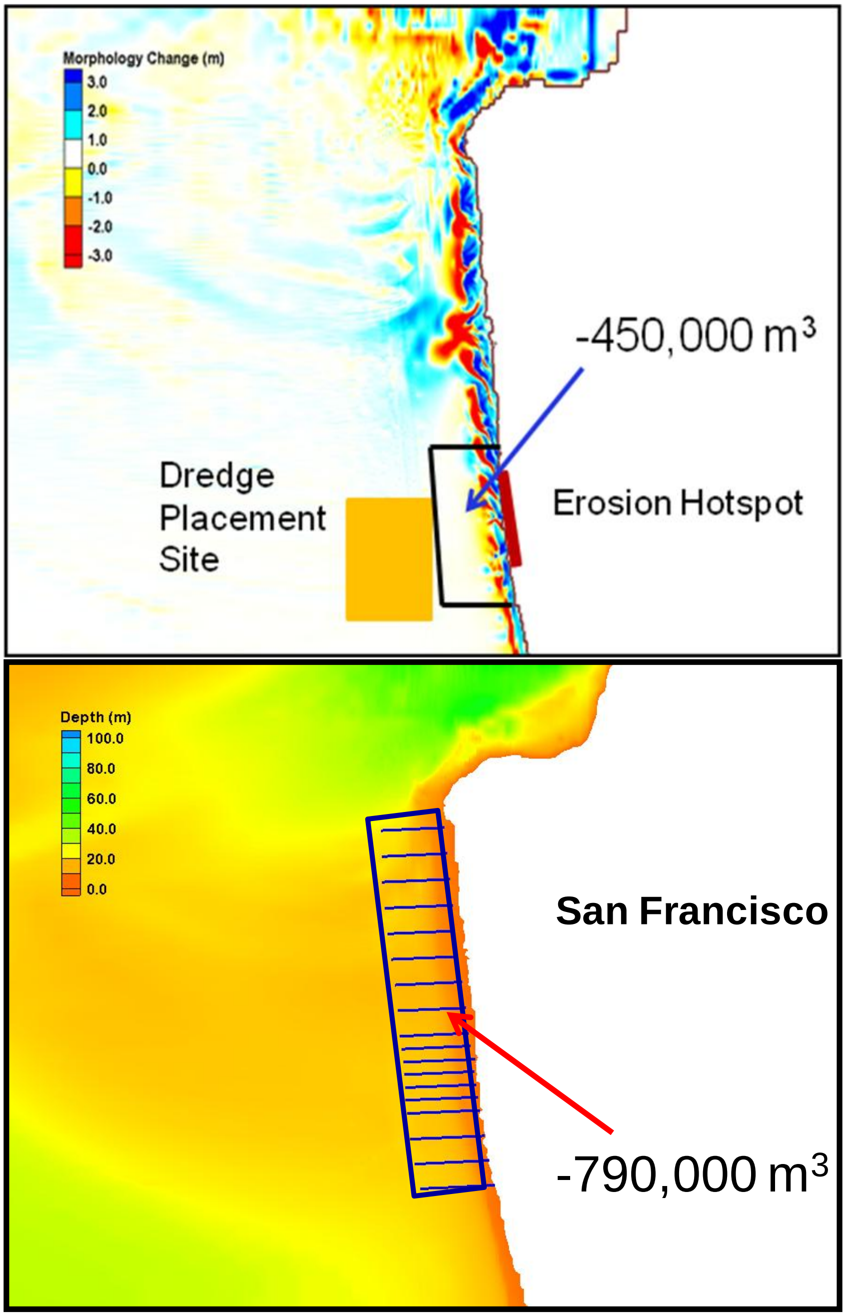

Figure 13. Morphology change and sediment balance after winter storms.

SUMMARY

A coupled wave, flow and sediment transport numerical modeling system, CMS, was applied to calculate sediment transport nearshore Ocean Beach in the San Francisco Bight. The CMS was calibrated against the measured waves, current, and water levels. The calculated sediment transport and morphology change were compared with the CPS observations.

The model results reflect a tide-dominated environment nearshore Ocean Beach during

the 10-day simulation from 20 to 29 June, 2005. The magnitude of tide-driven depth-average currents can reach 1 to 1.5 m/sec. Primary components of current are longshore whereas the cross-shore components are insignificant. Tidal currents carried sediment along the shoreline and generated significant transport from south to north during the winter month. Sediment volume change calculation indicates that sediment can move shoreward and greater erosion occurs between the Ocean Beach hotspot and the nearshore dredge placement site as winter storms passed the area. The sediment erosion rate obtained from the CMS results were validated via the sediment volume changes from the observations.

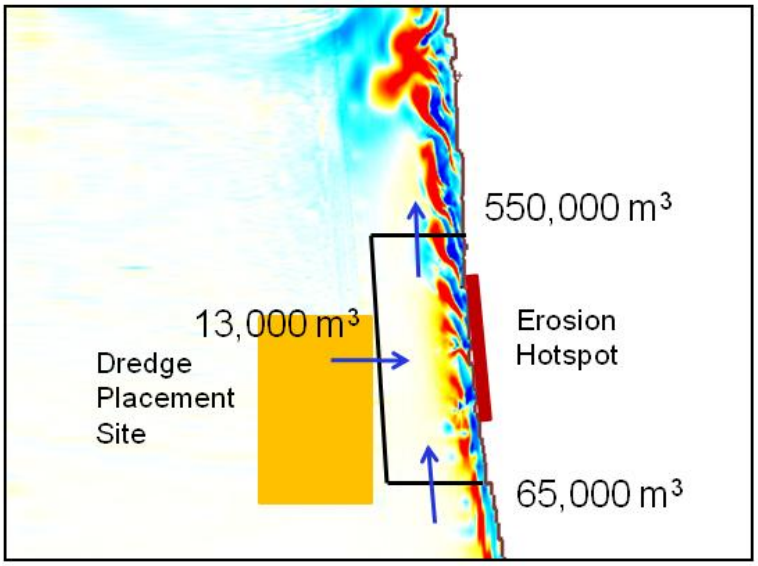

Figure 14. Sediment budget nearshore Ocean Beach.

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